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Review

Hydropower's future, the environment, and global electricity systems

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ABSTRACT

Hydropower is a well established electricity system on the global scene. Global electricity needs by far exceed the amount of electricity that hydrosystems can provide to meet global electricity needs. Much of the world's hydropower remains to be brought into production. Improved technology, better calibrated environmental parameters for large projects have become the norm in the past 15 years. How and why does hydropower retain a prominent role in electricity production? How and why does hydropower find social acceptance in diverse social systems? How does hydropower project planning address issues beyond electricity generation? How does the systems approach to hydropower installations further analysis of comparative energy sources powering electricity systems? Attention to the environmental impact of hydropower facilities forms an integral part of systems analysis. Similarly, the technical, political and economic variables call for balanced analysis to identify the viability status of hydro projects. Economic competition among energy systems requires in context assessments as these shape decision making in planning of hydropower systems. Moreover, technological change has to be given a time frame during which the sector advances in productivity and share in expanding electricity generation. The low production costs per kWh assure hydropower at this juncture, 2009, a very viable future.

Contents

1. Introduction

Water management emerged out of the agricultural revolution. Agricultural origins are associated with regions of water deficits. To foster productivity water had to be diverted to land to be sown. The urban revolution reinforced this process. Water management had rustic origins; it is the cumulative effect and the changes emerged that imparted growing significance to effective water utilization. Mesopotamia and the Nile valley were hearth regions for applied hydraulic manipulations. It is the industrial revolution that turned to use of hydropower to move machinery by means of waterwheels along stream courses to avail itself of this energy source. Hydropower at this juncture became a magnet for industrial location in the UK as well in New England. Even in Paterson, NJ in the early 19th century, the Great Falls served to power the local silk industry, the Colt (sixth-shooter fame), and the local locomotive factories. Hydropower for electricity generation had to await the convergence of scientific efforts of numerous researchers' experiments whose efforts matured to control and produce electricity. Faraday was the

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Table 1
1950 to 2000 world electricity systems installed MW increased by nearly 2,100% or about 42% /year. Worldwide increasing electricity dependence fosters larger generating systems and changing technologies advance electricity conservation.

	World Electricity Systems-World Regions-1950–1960 (MW, kWh/p/y)							
	1950				1960			
	Therm	Hyd	Tot	kWh/p/y	Therm	Hyd	Tot	kWh/p/y
World	102473	57360	154092	382	369957	149571	520,755	763
Africa	3062	485	3521	66	7285	1979	9264	128
Asia	7328	7584	14912	41	20119	16512	36631	122
Europe	55665	27355	83259	733	117262	53879	171885	1607
N. Amer.	N/A	N/A	N/A	2061	161375	53569	215253	3643
S. Amer.	2892	2164	5056	167	7225	6096	13321	349
Oceania	2045	944	2089	1019	4856	2755	7650	1960

	World Electricity Systems-World Regions-1970–1980 (MW, kWh/p/y)							
	1970				1980			
	Therm	Hyd	Tot	kWh/p/y	Therm	Hyd	Tot	kWh/p/y
World	817945	290652	1,125,392	1347	1403416	465396	2013006	1601
Africa	16608	7508	24116	244	29728	13170	42898	321
Asia	93995	42775	138537	279	226923	718218	324294	510
Europe	223934	99365	330832	3077	350619	137169	534763	4551
N. Amer.	321766	88114	416711	5934	547203	132180	742989	7611
S. Amer.	14416	14654	29070	564	26099	41914	68383	1131
Oceania	12896	6888	19976	3620	22598	10234	32992	5322

	World Electricity Systems-World Regions-1990–2000 (MW, kWh/p/y)							
	1990				2000			
	Therm	Hyd	Tot	kWh/p/y	Therm	Hyd	Tot	kWh/p/y
World	1771591	628429	2746127	2207	2230616	763808	3377828	2475
Africa	52370	19332	72742	486	77451	22104	101463	524
Asia	404973	120592	572942	817	750720	192269	1020013	1288
Europe	376809	171588	678338	5710	627616	241317	1055070	5168
N. Amer.	638100	160186	926446	8658	682143	178957	981638	10388
S. Amer.	34759	80375	116809	1504	52127	119149	165274	2055
Oceania	32890	12256	45750	10600	40559	13284	54370	8362

Sources: UN [25] energy statistics yearbook-1982, p. 684–710. Energy yearbook-1990, p. 456–473, energy yearbook-2000, p. 478–494.

first to achieve the production of electricity in 1831, but another fifty years were needed to produce electricity derived from a water powered waterwheel, invented by Francis in 1851. Hydropower's history covers 130 years, but its role in electricity use is disproportionate when the consequences are globally assessed. Electricity has become a pervasive, ubiquitous energy source in nearly all spheres of life. In the 21st century, virtually nothing functions without electricity, whether it's an electric tooth brush or a space shuttle, and everything in between.

Electricity dependence has reached near universal status. Dependable electricity availability has become a condition that shapes policies and challenges economic planning and production, necessitates environmental preservation, and fosters energy-electricity conservation. Electricity can be produced in numerous ways in terms of resources used, such as oil, gas, coal, geothermal, biomass, eolian, nuclear, solar, and water, as electricity enters the transmission system, it is impossible to tell its source of origin, especially when numerous different sources are used. It is the availability and dependability of the electricity driven resource that matters as the per capita consumption rises globally inexorably (see Table 1).

Hydropower's future has to be considered as a transition stage for many states of the world that have fluvial systems that can be drawn into the electricity generating system. Environmental conditions, political planning, economic options, available technical personnel, existing electro-mechanical industries, and energy-kind competition, each of these variables shapes the decision-making process when, if and where to place such electricity generating utilities. Hydropower plants turn out to be very long term projects, hence their future is planning dependent and anticipated economic viability measured. Electricity systems will exist for the predictable future; it is the energy source(s) that may change radically. In this context, hydropower may serve for a longer time as major "energy bridge" to a different energy future.

2. Purpose of study

With most of the world's hydropower potential available for near future development, it is local interests and sovereign states that decide how to manage their water resource base. Hydropower projects require prolonged planning and construction periods. Governments change, electricity needs shift, and increase but the basic physical conditions tend to retain their physical characteristics for a predictable time span. Given the increased environmental awareness, why and how do hydropower systems continue to find social and political acceptance in diverse social systems? How does hydropower project planning address issues beyond electricity generation? How does the systems approach to hydropower installations further analysis of comparative energy sources powering electricity systems? How compatible is hydropower with the changing energy matrix? Hydropower installations appear in phases, in response to electricity demand and a state's preparedness to absorb the added electricity supply. It is in the BRIC (Brazil, Russia, India, China) states where this progression can be represented in regional and chronological detail. And technological changes in hydropower have to be anticipated, such as hydrokinetic systems, e.g.

3. Hydropower as instrument of change

Hydropower turned into an instrument of production change, powering the beginning of the industrial revolution, notably in the

Table 2
Select river basin data for annual water availability.

Region	River basin	km^2	Water (km^3)	km^2/km^3	Mean Flow (m^3/s)
Asia	Yangtze	1810000	1003	1805	35000
	Ganges/Brahmaputra	1750000	1389	1260	20000
	Indus	960000	220	4364	3850
	Mekong	646000	459	1407	15900
	Armur	1860000	355	5240	12500
Europe	Danube	578300	176	3286	6450
	Volga	1360000	252	5397	8000
	Pechora	317000	137	2314	4060
	Rhine	103700	50.6	2050	2200
Africa	Niger	2090000	302	6920	5700
	Congo	3680000	1320	2788	42000
	Nile	2870000	161	17826	1584
North America	Mississippi	2980000	515	5786	17545
	Columbia	668000	237	2819	6650
	Colorado	637000	16	38813	168
	St. Lawrence	1026000	320	3206	10400
South America	Amazon	6920000	6920	1000	180000
	Parana	3100000	811	3822	19500
	Orinoco	1000000	1010	990	28000
	Bio Bio	21220	36	596	1230

Source: Ref. [22], p. 5–6, 68, 124, 190, 247, 307.

UK Midlands. Then it was waterwheel powered with driveshafts to activate textile production. In Brazil, at Juiz de Fora (1889) one of the first hydroelectric plants powered a textile mill. Numerous technological changes were needed to achieve greater electricity transmission distances, which freed machinery from transmission belts and introduced the dynamo driven individual machines. Hydropower served as an electricity provider in the industrialization process in France, Germany, Norway, the UK, Italy, and the US. After World War II, Brazil started to foster hydropower projects to serve the major urban cores and the beginning of industrialization [1]. Coal rich states such as the UK, USA, and Germany used hydropower and coal powered thermal plants, but coal-poor states such as Italy and France turned to their "white coal," the hydropower resource base.

For hydropower-rich states such as China, India, Russia, and Brazil, hydropower construction in phases served to promote industrialization. Lenin as early as 1920 borrowed from a friend "...The age of steam is the age of the bourgeoisie, the age of electricity is the age of socialism." [2]. The post World War II industrialization of Japan, S. Korea, and China without hydropower would have had a different pace then actually recorded. It is economy of foreign exchange that plays its part. China has actively fostered its hydropower sector dating to the 1970s, and currently it is the premier hydropower in the world. Similarly, much of the USSR's industrialization was hydropowered. Hydropower serves as an instrument of change and in most instances it is a domestic energy source that fosters exchange rate savings, but also encourages the formation of a domestic electro-mechanical heavy industry to provide the mechanical equipment that can be domestically manufactured (e.g. Mecanica Pesada, Brazil). Another essential component of the hydropower system is the electricity transmission infrastructure, the less complicated component to produce locally. Hydropower turns into an instrument of reciprocal, complementary benefits, providing essential electricity and supporting a host of electro-mechanical industries.

4. Water management-hydropower and water availability

In the popular perception, hydropower dominates in the world of river regulation. In the numerical context, hydropower in total river water management at this time regulates about 12% of the world's rivers fluvial volume (Chao [4], see also [3], p. 366). It is the evolution of large dams, 1000 MW and larger, which create notable reservoirs. Among the first of this scale is the Hoover Dam, 1951 MW and now there is the Three Gorges Project, 22,400 MW. One of the largest reservoirs is Lake Nasser with 160 km^3. Actually, 88% of the world's stored riverwaters serve urban water supply systems, irrigation (which uses 70% of the world's fresh water), flood control, recreational water projects (in the US, this is 36%), and canal systems ([3], WATER, 366).

Water management is a most sensitive subject matter. In undergraduate economics, the economics professor (1950) pointed to water as a ubiquitous and free resource, offered as example of a costless factor in economic analysis. Times have changed. As per capita water consumption increases with changing global urbanization rates, it may become necessary to identify priority ranking for water uses. Implicitly, a water conservation categorization may foster voluntary per capita use reduction in general populations. Water-pricing would encourage increased conservation by means of direct personal economy. Even hydropower plants may have to pay for water use and charge more for electricity to achieve balance in water utilization rates.

Hydropower's water dependence is precipitation and river volume contingent (Table 2). Precipitation totals expressed in km^3 for the specific watershed provide the hydroproject planner essential parameters for project planning. Another measure that project planners are keenly interested in are streamflow values in m^3/s. These are closely related data, but topography and streamgrade influence rate of runoff and speed of streamflow. Water availability may be evaluated on the basis of the km^2/km^3 ratio as the ratio gets into five digits, electricity generation tends to lose dependability in contrast to three digits when the generating potential gains in predictability (see Table 2). For the world this kind of data collection is uneven in quality, quantity, and time gathered. Data gathering, reporting, and publishing comes with the culture of scientific inquiry, and with scientific experimentation. The absence of this basic data for use in hydropower planning impacts adversely, technically, economically, socially, environmentally, and politically. Sound water management under the circumstances stands significantly compromised.

The data serves to restrain hasty assumptions about climate as a determining consideration for setting up hydropower projects.

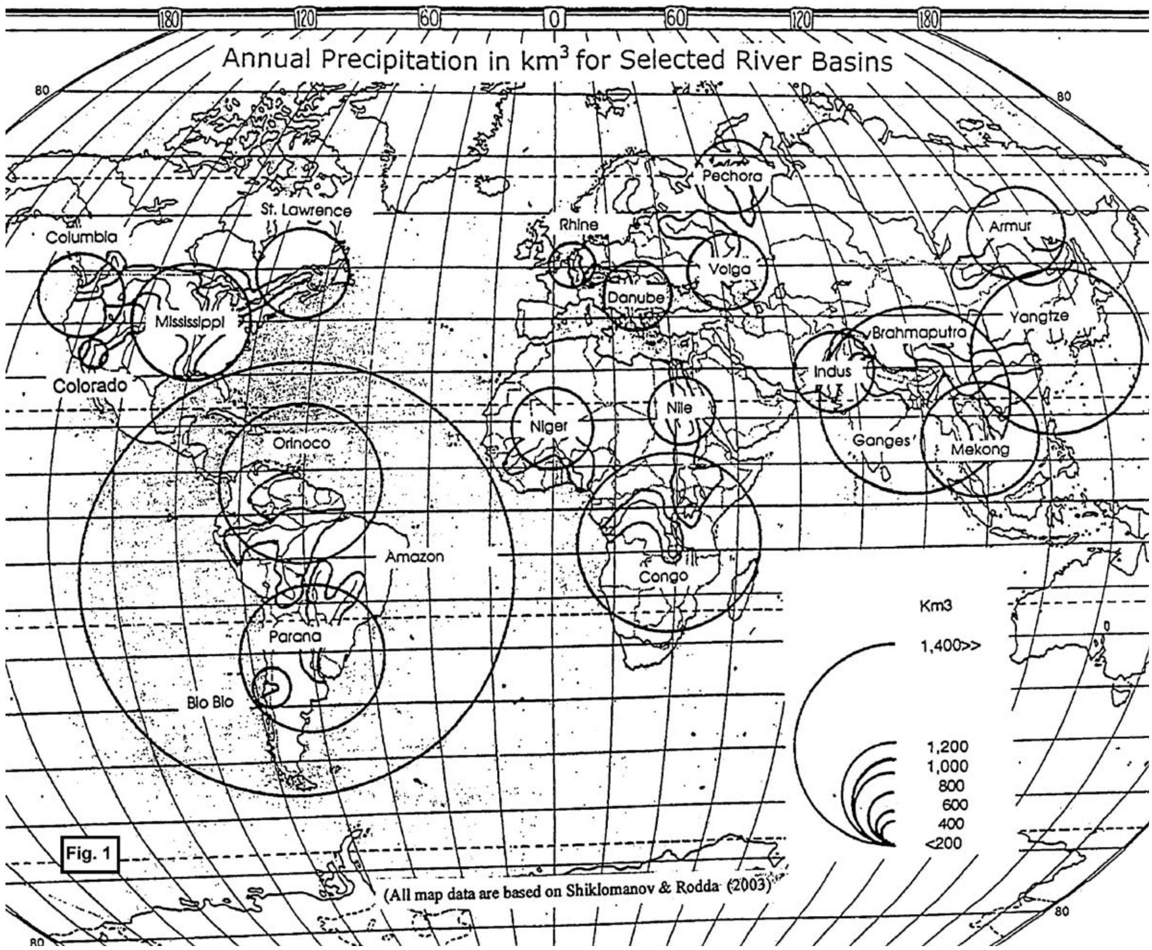

Fig. 1. Selected world river annual discharges in km^3.

Possibly one of the more favorable rivers for hydropower projects is the Bio-Bio, Chile, as 1 km^3 needs less than 600 km^2 in area of surface (see Table 2), and Pange is a top revenue producer per hectare of installed power, about \$90,000/year/ha at 57% of installed capacity. The Itaipu experience, different in scale, is exceptional, as it often generates above installed capacity. Water management for hydropower is subject to local norms, a global formula proves elusive to articulate as regions and sites tend to uniqueness.

An overview of some of the world's major rivers, their watershed areas, the approximate amounts of precipitation as recorded in km^3, and their drainage area are reported in km^2 and approximate streamflow values provides tangible reference points for hydropower planning (Fig. 1). At this time, the Amazon River volume is less useful for electricity generation than the Colorado River with its 16 km^3/year water accumulation versus the Amazon's 6920 km^3/year (see Table 2, Fig. 2). How does the Blue Nile (Ethiopia) contribute to the Nile main channel, and for how long have the Ethiopians had dependable data to manage the national hydropower resource base effectively? In this part of Africa, evaporation rates enter the hydropower planning assessment when Lake Nasser yields 14–15 km^3 of water to evaporation a year (or about 440 m^3/s). One of the more hydropower generating rivers of reference in the table is the Parana-Paraguay-Uruguay-La Plata system, which in the Brazilian segment has 42 hydropower projects. The headwater dam Furnas tends to be a key control unit for down-river volume of water and velocity, hence as the water moves downstream, each subsequent dam registers a certain increase in its generating rate. Engineers assume 50–57% average of firm power yield for the year, or a 1000 MW unit is projected to generate 500–570 MW on a continuous base load for the year. At Itaipu, 75–90% yield are the norm, or 12,500+ MW at 90% daily (675,000 barrels of petroleum/day). 675,000 barrels of petroleum per day = \$33,750,000/day at \$50, for the year that equals \$12,319,000,000. (It is unwise to use a higher petroleum value, as market fluctuations should constrain unrealistic claims). In five consecutive years the capital generated comes to \$61,593,750,000.

The two maps of precipitation in select river basins expressed in km^3 and stream flow per second in m^3 for selected rivers (Figs. 1 and 2) point to improved resource utilization possibilities with a less environment intrusive technology. Time and investment will be needed to develop run-of-the-river turbines, a form of damless hydroelectricity system. This is a challenge for the next three to four decades as an increase in fossil fuel reduction for multiple resources will gain in global acceptance (merely consider one state burning 2.3×10^9 tons of coal per year out of the world 5.3×10^9 tons per year: see [4], p. 78). This kind of electricity generating system would be most appropriate initially for very large river system, with the watersheds registering receiving above the 1000 km^3/year mark.[1] The stream flow data are the more informative to assess hydroelectricity generating potential. To this have to be added local geomorphology, notably streambed morphology and river grade. (An excellent source for specific river studies is [5]. Many of the rivers mapped are considered in detail in the text). With notable variation in river grade naturally, the one

[1] In August 2008, Itaipu was operating at 12,500 MW/day or 90% of installed capacity. Itaipu at this time operates as a run-of-the-river unit.

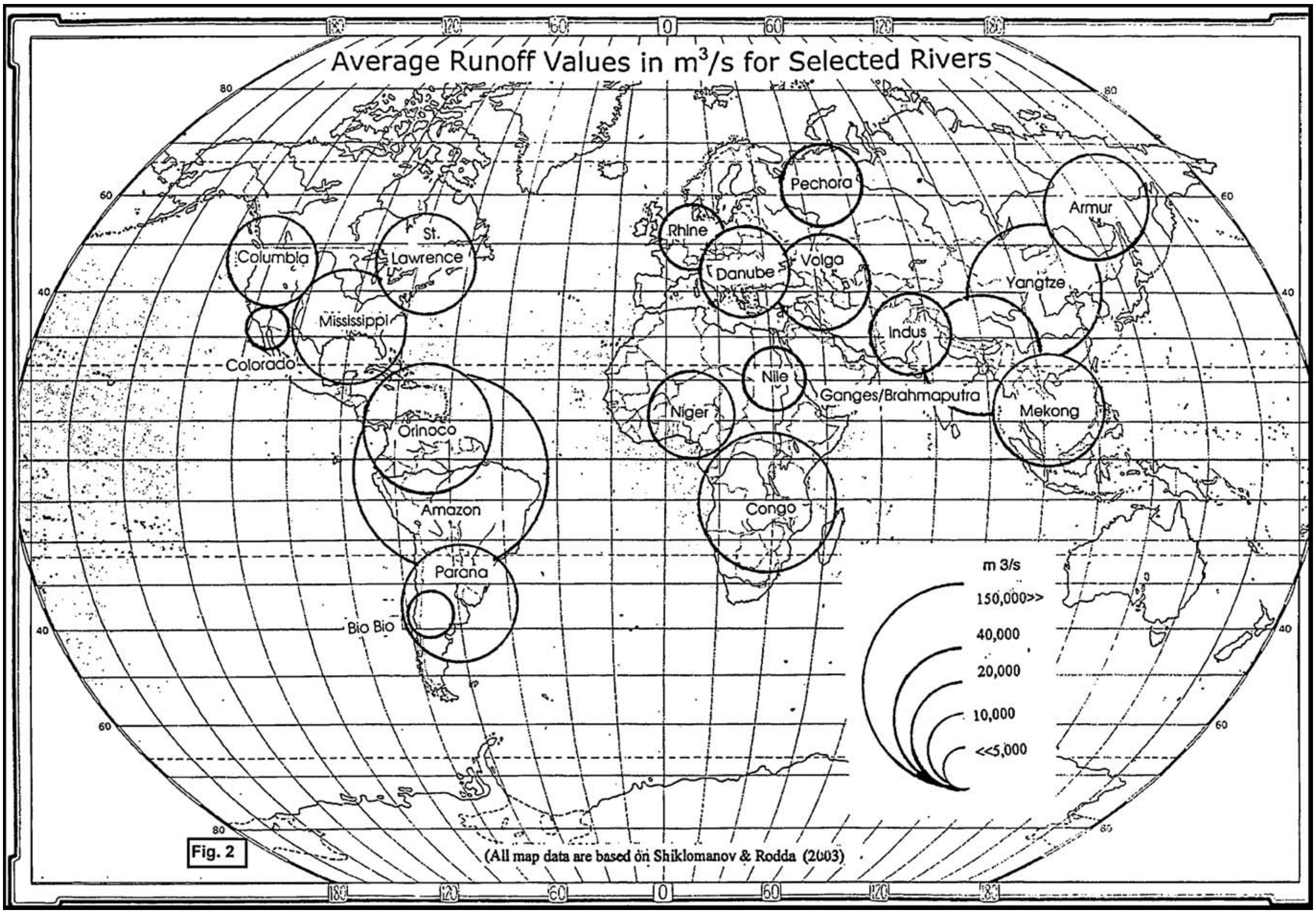

Fig. 2. Selected world river per second m^3 stream flow at key control stations.

created by hydropower dams adds to stream velocity variations between dams and corresponding inter-dam distance variation. The steeper the grade between projects, the more attractive the possibility to install damless turbines with better than average water availability and speed for power generation.

Instead of individual dams with specific name-plate installed potential, it is essential to find the approximate size turbine and rotor for certain water volume and river speed to fit into the specific river system. The next step involves optimal separating turbines in the context from upstream to downstream to retain even water speed and pressure for operating efficiency. Placement of the units could be achieved by devising a factory ship that places the supporting pylons, turbine installation, and platform for attaching to the rotor system. Transmission line development would include essential consolidating transformer station locations to up the kV dispatched over longer distances. This more active use of transmission could result in more efficient transmission delivery in the form of notable reductions of electricity losses during the transforming phases, the consolidating one, and the receiving end the transformer station, where transformation generally registers a 7% electricity loss. Numerous technological hurdles have to be overcome to achieve improved returns on these possibly massive projects.

In the project planning process productivity dependability comprises a notable aspect to identify the scheme's long term viability. Stream-flow data and watershed areal extent afford a measure to approximate water volume availability of a specific river segment. As noted above, the larger the surface required to gather runoff, two conditions become apparent: one, the reservoir has to be proportionally sized to store ample seasonal precipitation accumulation to allow a minimal operational timeframe for the installed generating system; and two, the larger drainage surface surrenders a higher percentage of the precipitation to evaporation losses. A project in a watershed area where 1 km^3 needs 600 km^2 compared with a drainage shed of 6000 km^2/km^3, informs the project planner of potential water availability a potential generating time frame for operating parameters of kWh. Function of the dam in the river system identifies actual watershed areal extent. There is the headwater project and then there is the dam closest to the river estuary, which includes the river's entire watershed. Tucurui registers about 11,200 m^3/s or about 352 km^3/year, or the Tucurui watershed of 758,000 km^3/year translates into 2152 km^2/km^3 of precipitation in its watershed, the daily average that transits Tucurui is .96 km^3. The Madeira, a tributary to the Amazon, at Porto Velho, averages 19,000 m^3/s, or, 599.2 km^3/y. Its drainage area is 903,500 km^2 or 1505 km^2 of surface collects 1 km^3 of stream flow/year, and 1.64 km^3 on average transits Porto Velho daily. Each project can be assessed in this way to project its generating production parameters. The Bio Bio Pange Dam, can be considered among the most productive. Itaipu and Xingo (both are in Brazil) are run-of-the-river projects and need to be considered in a different analytical context.

With the possible reduction upon dam dependence along river courses, and significant economy in project expenditures, the flooding of productive land or population resettlement would become unnecessary and it would be economically rewarding and be socially constructive, as no resettlements would be called for. Fish life and river transport are other variables that need to be addressed. For protection of fish life there may be forms of barriers that deflect fish to be drawn into the turbine draft. For navigation

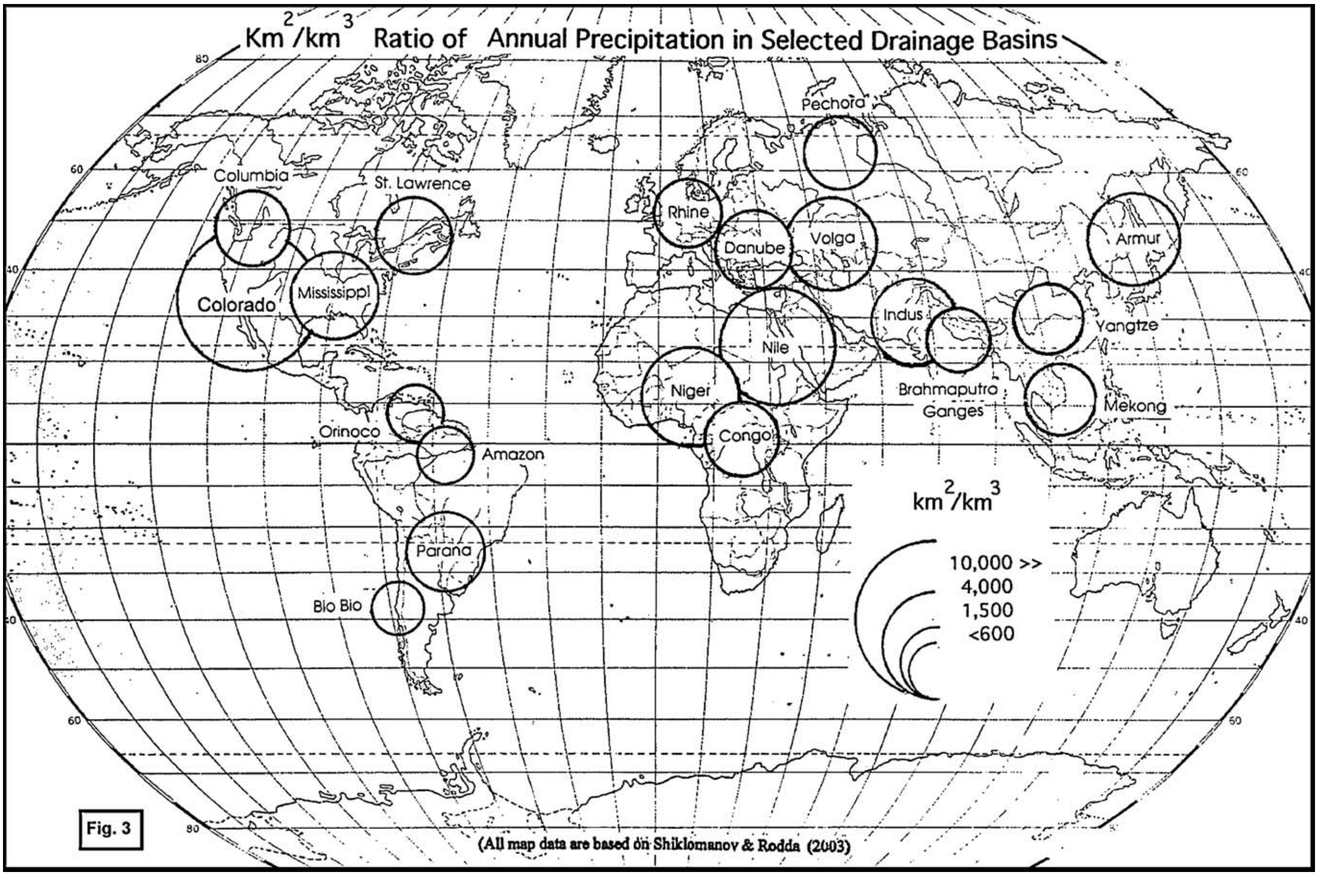

Fig. 3. km^2/km^3 provides an approximation of water availability, this information can serve to assign reservoir size by the respective project engineer(s).

the turbine pylons could serve as guides instead of needed buoys. The environmental impact of this system is an unknown. Until a system is in place and its function has been monitored for a decade, any assertion is inappropriate at this stage of knowledge. In most likelihood this system could be the least environment damaging energy system available.

Figs. 1 and 2 provide a comparative overview of select river basins. Fig. 3 affords a measure of how much precipitation in km^3 is registered in a specific watershed. What the data does not include is the soil moisture absorption rate or the local evaporation losses. The ratio of km^2 to km^3 provides an additional parameter of stream flow assessment and predictability. The larger the catchment area per km^3, the more uncertain the streamflow regime. From Table 2, the least reliable river listed is the Colorado, which depends upon over 38,800 km^2 per km^3 of registered precipitation, the Bio Bio in Chile drains 596 km^2 to collect 1 km^3 of precipitation. The data point to a possible streamflow reliability measure namely the lower the ratio the more productive the hydro potential of this river. The rivers listed for South America in this table register above average values, notably the Bio Bio and the Orinoco. The mean value for the selected rivers is 5585 km^2/km^3. Four of the rivers included in the list exceed the average registered, and two of these, the Colorado, U.S., Nile, Egypt, Sudan, Ethiopia, and Uganda are seven and three times exceeding the average. It can be said that the lower the measured ratio, the more dependable the river's productivity potential.

5. The environment and hydropower

Constraint in a river system will lead to multiple modifications in its metabolism and its environmental fabric. Actual extent of environmental change depends upon project magnitude, in the case of hydropower it is generally the reservoir size (volume and extent) rather than the installed generating hydropower project altering area project morphology (that affects the larger project area). Two Brazilian projects serve to illustrate different aerial project morphology. Serra da Mesa, head dam on the Tocantins has a 54.4 km^3 reservoir (Serra da Mesa installed potential is 1998 MW); Xingo on the Sao Francisco, 3000 MW installed, 5000 MW potential, is a run of the river project, essentially without reservoir as it reworks the turbined waters from the up-river Paulo Afonso system. This affords an overview of the range of differences that are hydropower project associated.

Emphasis is on hydropower, and the environmental impact is project size related. Reservoirs for example in Amazonia generate less humidity than the natural vegetation, which impacts the original precipitation pattern. Forest removal in planned reservoir areas in the Amazonian environment has proven difficult because of the rapidity of the regeneration of secondary growth. Forest inundation produces eutrophication and its dissolution depends upon the streamflow regime in volume and velocity. The more frequent the renewal of the reservoir water, the sooner the eutrophication process can be attenuated and in time restore the water body to functional health. At Tucurni, Tocantins River, Brazil, the reservoir water is renewed about every 47 days, nearly eight times per year, Balbina dam, Uatuma River, Brazil, requires at least one year to recycle its reservoir volume.

Sedimentation is generally part of the natural drainage process from runoff. There is far more complexity to the topic than can be addressed, but a key agent is active land uses. Agriculture, roads, forest clearance, urban systems, rank high as sedimentation agents. Hydropower planners cannot accurately predict the sedimentation rates since land use management practices are uneven in much of the world. Hydropower managers share the

topic at meetings and special symposia, addressing the complexity of the issue [6].

Continuous expansion of the hydropower systems into open river systems points to conditions of electricity demand for which an effective response has to be found locally. Rising electricity demand and increasing electricity costs point to the shrinking options to policy makers on how to balance environmental conservation and electricity demand. Hydropower professionals are turning increasingly environment sensitive and hydropower projects are designed to minimize environmental stress. In Brazil, the Madeira project is for a 15 meter high dam, or a barrier that limits the reservoir to the floodplain accepting bulbar turbines of 72 and 75 MW each ([7], 77ff). Future hydroprojects can be expected to differ from antecedent projects and be less conspicuous in the physical landscape.

6. Hydropower and changing electricity economies

Investment resource availability shapes future electricity generating infrastructure. A convergence of multiple interests mold future plans in the hydropower sector and its corresponding construction schedules. Heterogeneity in the resource base of the world's states, varied stages of domestic infrastructure formation, notably different lifestyles and cultural contexts, and uneven environmental perceptions affect broader generalizations about hydropower's future [8]. As hydropower projects gain in magnitude, so do the needed investments which have to anticipate returns for the long term. Given these conditions, governments become increasingly the key agencies as paymasters for the key hydropower projects. In the US it was the Hoover Dam, the TVA system, the Columbia River system, and the St. Lawrence River projects that can be cited as government sponsored. At the international level reference can be made to the multiple hydropower projects along the Danube, or in the La Plata River system. The latter home to three projects has grown into MERCOSUR, a regional supranational economic union.

Cost assessment is generally on price per kW installed. Economy of scale favors large projects as it lowers the cost per installed kW. Emphasis is on the generating facility, but implicit in general consideration is the availability of transforming stations and transmission lines. While these cost elements are not addressed here, they form an integral part of the generating system, the dam ([9], NETWORKS, 233–261). In the planning and execution phase of hydropower projects, their construction phase is compressed in time, it is the hydropower project that is a time costly, or the interest charges that consume large sums that play their part in compressing the construction schedules. Hydropower project planners, depending upon project size, have to include a time horizon of 30–50 years to insure project economic viability. While these professionals address project economic viability, the larger horizon is serving the public needs of a specific country. Larger projects tend to become part of the national budget, hence these projects turn into public property.

Mega projects mobilize a large labor force to foster timely completion of the power plant. If 30,000 people work on such project, allow five to ten years before the first turbine of many comes on line. That means that during these years, payrolls to be met without any income from such projects. And the additional turbines, depending upon their respective size, each generally takes four to six months to install, so when a project has 10–20 turbines, another five to eight years are needed to complete the project (see Figs. 4–6). At this point, it is easier to explain the initial high cost of hydropower, it is the hiatus of no income to the last unit coming on line. Private investment cannot sustain such investments without income producing operations which clarifies why major projects tend to be publicly owned ([10], "LATINAMERICANIZATION.").

Fig. 4. Itaipu-Binacional an upstream panoramic view. There are 20 installed generators of 700 MW and 18 of these are in continuous operation with two as standbys in case of outage. In August 2008 daily generation averaged 12,560 MW, or 90% of installed capacity. The plant can be considered a run-of-the-river unit. Source: Rolf Sternberg.

Fig. 5. Standard transmission towers out of Itaipu-Binacional, these are 500 kV lines, which feed into a transformer station where the electricity is converted to 600 kV, DC, and 750 kV AC for delivery to key consuming poles. Source: Rolf Sternberg.

Much of economic development worldwide has been hydropowered, whether it came off the waterwheel or from the hydropower plant. In South America urbanization has been largely hydropowered, and that came from government coffers. Hydropower finds general acceptance as a domestically available energy source. The term "white coal" comes from Switzerland and Italy, two states without domestic coal resources, but with extensive fluvial systems which provide actively used hydropower potential.

In the 21st century electricity has become a dominant energy source. Its costs reflect the source from which it is derived, hence while the kWh has one price, its production costs are source dictated. At this time hydropower derived electricity continues to be the lowest cost electricity available world-wide (Table 3—Energy systems, p. 501 [11]). Hydropower cannot be expected to meet the world's electricity needs, it serves as "energy bridge" to a technology manipulating world. It contributes to infrastructure formation, transmission systems, transformers, and influences electricity pricing.

Table 3
Illustrative estimates of the environmental external costs (in pence per kilowatt-hour) for electricity production from selected energy sources.

Cost category	Old coal	New coal	Oil	Gas	Nuclear	Solar	Wind	Hydro
Health								
Mortality	0.32	0.32	0.29	0.02	0.01	0.07	0.04	0.03
Morbidity	0.12	0.12	0.12	0.04	0.01	0	0	0
Disaster	NE	NE	NE	NE	0.45	0	0	0
Crop damage	0.10	0.05	0.05	0.02	0	0	0	0
Damage to forests	0.84	0.07	0.98	0.03	0	0	0	0
Reduction of biological diversity	NE	NE	NE	NE	NE	NE	NE	NE
Damage to buildings	3.22	0.28	3.77	S.I.I	0	0	0	0
Noise	NE	NE	NE	NE	NE	NE	NE	NE
Global warming damage	0.40	0.34	0.35	0.16	0.01	0	0	0.01
Visibility impact	NE	NE	NE	NE	NE	NE	NE	NE
Water pollution	0.40	0.04	0.049	0.01	0	0	0	0
Land contamination	NE	NE	NE	NE	NE	NE	NE	NE
Total	5.40	1.22	6.05	0.39	0.48	0.07	0.04	0.04

NE: not estimated but probably positive. (Source: Adapted from Pearce et al., 1992.) (Source: Boyle, (2003) ENERGY SYSTEMS, p. 501.)

Fig. 6. Itaipu-Binacional command center. There are generally 3–5 engineers on duty serving the respective national sector, Brazil and Paraguay. This center is located in the mid-section of the powerhouse. Source: Rolf Sternberg.

As fossil fuels increase in price, plus their polluting byproducts, the hydropower resource gains in appeal economically and environmentally. While the world's coal reserves at present consumption rates may readily serve another several centuries, the cost factor will change, a similar consideration applies for petroleum and gas. Unpredictable cost conditions in the fossil fuel sector in contrast to the stable hydropower sector points to the continuous expansion in the hydropower sector. Emphasis upon significant reductions in fossil fuel pollution will contribute to modify the energy matrix, providing a larger berth for a renewable energy source such as hydropower.

Electricity is a metered commodity. Its output is registered with notable accuracy, hence its pricing is calibrated with an accountant's finely pointed pencil. In a world of multiple energy sources, competition for market share cannot be neglected. Project costs, electricity markets and electricity prices are all variables that enter hydropower project plans as these have to anticipate within the limits of prescience what the electricity market will be for the coming two or three decades. Assessments of projects are cost-based, equally important to assess is the multiplier effect of hydropower for the economies to which these deliver the electricity. Isard provides a lucid analysis of the multiplier principle, to disentangle the hydroelectricity contribution to employment remains elusive considering the lack of focused studies ([12], p. 284–5).[2] What is the impact upon industrialization, urbanization, transportation, standard of life, the environment, and conservation possibilities? Weber in the study ITAIPU E O PARAGUAI creates another perspective of the multiplier effect as it changes a national economy.[3] By using 1970–2000 period national economic data the author illustrates annual growth rates for the Paraguayan economy exceeding 7%. Large projects have a transformative impact upon national systems extending well beyond the economic, affecting the educational system and the social milieu adapting changing conditions. Electricity is a closely metered clean energy source that confers prominence to the hydropower sector.

7. Hydropower and governments' energy plans

Governments are drawn into the hydropower sector as societies increasingly demand public services. As life styles change and gain in complexity, the spatial organization of services leads to hierarchization and tends to reach to the farther limits of the state. Among the public services, water can be identified as the leading sector, in the 21st century electricity's functionality has given it a preeminent position in productive social systems. In the capital economies there is the convenient dichotomy of the private and public sectors (Sternberg, op. cit.). Necessary infrastructure with delayed returns is left for governments to implant. Hydropower is among this group of monumental investments that the private sector likes to build and use, but not invest in. Governments get into the hydropower sector to advance the welfare of society. In the US reference can be made to the TVA or the interstate highway system, in Turkey, Iran, China, and Canada governments are identified with large hydropower projects. Governments are anticipating electricity demand essential for viable economic change as locally expected ([13], "The Role" 651, and [14], "Chinese Hydro", 71) (Table 4).

Governments embark upon electricity generating facilities not so much as an electric utility firm, but as an agency that fosters the creation of needed infrastructure to support and advance national needs and interests, TVA served regional needs, promote infrastructure formation, set standards for electricity rates and promote local employment opportunities and foster environmental conservation. What firm has the capital resources to build a 5000 MW dam? By capital market standards what would have to be the price per kWh to the consumer? Governments turn into first and last resorts for mega projects. Since much of the electricity will be used,

[2] Isard et al. [26] METHODS, 190–213; Isard (1956) LOCATION, p. 284–5. A more applied approach to the multipliers are considered in Perloff [20, p. 93–6].
[3] Weber [27] ITAIPU.

Table 4
Projected electricity demand for selected states—2004–2015 in %/year.

Africa (%)	
Cameroon	5–6
Congo	3
Kenya	6
Libya	6
Mozambique	6–8
South Africa	4.8
Zambia	3
Europe (%)	
Austria	2–3
Bulgaria	3
Czech Rep.	2
Finland	1
Norway	1–2
Romania	15
Spain	3
Germany	0.5
Oceania (%)	
Australia	2.8
New Zealand	2.1
Asia (%)	
Bangladesh	8
China	3.8–5
India	6
Iran	6
S. Korea	3.6
Pakistan	6
Russia	2.9
Turkey	7
Americas (%)	
Mexico	5.6
United States	1.8
Argentina	4.8
Brazil	5.1
Chile	5
Columbia	3–4
Peru	5.6
Venezuela	4–5

Bartle, a (2004, 2006) world atlas and industry guide.
World Survey Selections Sutton.
Sutton, Surrey, Agua-Media International.

Table 5
Select world hydropower development data for 2008 and country data beyond 2008.

Region	2008	Beyond 2008
World	157803	344176–461257
Africa	7489	24236–84048
D.R Congo	162	3600–43000
Ethiopia	1277	7280
Nigeria	3300	950–11500
Asia	130479	224368–241699
Bhutan	1209	2417–10320
China	80000	65000
India	15371	34000
Iran	4500	17500
Oceania	160	416–2489
Europe	2408	11029–13820
Norway	432	2783
North America	5940	18435–43645
Canada	2600	12000
Mexico	2250	2400
South America	11327	65693–75556
Argentina	382	9000
Brazil	5500	33000
Venezuela	2699	0–7710
Russia	7000	12000
Turkey	3962	>19000

The International Journal on Hydropower and Dams (2008), 2008 World Atlas and Industrial Guide.
Source: Surrey, UK, 15–7. Values expressed in MW.

it also becomes available to households, most of these are perhaps at the low end of the savings level, hardly within reach of making shareholder investments. Governments turn into project development agencies. In Brazil it was the federal government that got into the electricity sector via Eletrobras and it served to turn Brazil into an industrial state and ended foreign private sector overseen brown and black-out episodes.

In recent years China, Turkey, and Iran have committed large capital resources for the construction of large hydropower projects. Note, this is Asia, where massive hydro resources remain to be brought into electricity generation. Vietnam, a rather small country, has 17 units that are in construction, and 10 of these are 100 m or higher. Out of 95 dams in varied stages of construction in China, 50 units will exceed 100 meters in height, and 10 of these have an installed potential of 1000 MW plus. Iran has 48 projects under construction and of these 16 exceed 100 m in height, while in Turkey 15 hydropower projects are under construction that are exceeding 100 m of height out of 51 units.[4] Japan has 35 units in varied phases of construction of which eight exceed 100 meters in height. Most surprising of these different data clearly is Iran (see [15], 179–182), one of the world's leading petroleum producers.

[4] The pace of dam construction in China can be grouped by data reported in Ref. [21]; in 2008 175 units were completed, 198 were in construction or planned. The on-line units were rated at 116.7 GW. The pressure to turn to hydropower can be traced to rising energy prices and their multiplier impacts.

Different states assess their resource base within a particular frame of reference and identified local needs ([16], HYDROPOWER AND DAMS in the Russian" 148ff). Governments are drawn into hydropower construction via the public service route to further the domestic economic system. This is also known as the national interest (see Table 5).

8. Hydropower-geopolitics

Hydropower's future is difficult to insulate from geopolitical streams and interest groups. Geopolitical contentions can be domestic as well as international. Riparian rights in fluvial systems are the more immediate friction zone. One has to allow for different energy groups to consider large hydropower projects as potential challenges to electricity rates. The geopolitical arena accommodates a multitude of contending parties, the parties to the events have an agenda to advance their particular interests. While this forms part of infrastructure formation, experience has shown that positive outcomes are both achievable and mutually beneficial. The process may be drawn out, parties in time find compromise a means to meet their respective needs.

Over the years, Canada and the U.S. resolved their differences on the use of the waters of the Columbia River and the St. Lawrence. The Danubian states over time have managed to coordinate their respective hydropower and navigation needs pragmatically, Uruguay and Argentina first considered Salto Grande in 1903, but its construction started in 1974. The pace of change is in good measure powered by the pressure of electricity demand and economic-social requirements.

Itaipu-Binacional affords an idea how geopolitics can be put to productive use for the national interests. The idea existed for some time, but by 1967 Brazil realized the national electricity demand was out-pacing the hydropower project construction schedule. At the time Brazil imported 90% of its petroleum and its coal resources

are small and high in ash contents and low in calorie output. This led to the study of Itaipu in 1967, and by 1973 the Brazilians and Paraguayans agreed to its construction. The Argentines invoked riparian rights, notably with the height of Itaipu reducing the potential of Corpus Cristi from a projected 5000 MW to 4000 MW at Eldorado. The polemics out of Argentina made no impression upon the Brazilians or the Paraguayans. Construction of the project started in 1974 with preparation for the diversion channel. Dam foundations started in 1977, and by 1984 the first turbine of 20 came on line. To move a project of this magnitude into construction within ten years provided the Paraguayans with a level of equality unlikely under virtually all other conditions ([17], APUNTES). "Equality" served as key, whether in number of workers, houses, key decision makers, or electricity sharing once electricity generation came on line. Only in finance was Brazil the privileged provider.

In time the Argentines and the Paraguayans agreed to build Yacyreta west of Posadas. Currently there are three large hydropower projects shared by four states, in the La Plata Basin, Salto Grande–Argentina–Uruguay, Itaipu–Brazil–Paraguay, and Yacyreta–Argentina–Paraguay. Out of this coordination of shared hydropower projects among the four Southern Cone states emerged MERCOSUR. The hydropower projects illustrated to the participants that regional integration of shared resources contributed to the national needs and interests of the participating states. Argentina and Brazil share plans to build at least two large units above Salto Grande on the Uruguay River. Here, geopolitics illustrates how to move from contention and conflict to regional cooperation. These hydropower projects change the spatial order of the region in the major spheres of politics and economy.

9. Hydropower's future in a fluid energy world

To predict the future is comparable to purchasing a lottery number and then mortgage the expected winnings to a dwelling anticipating to win the pot. Time parameters need to be clearly identified to impart meaning to the prediction of hydropower's future. Hydropower in different countries is in varied phases of utilization of the respective states' hydroelectric potential. Myanmar in 2000 had 365 MW of installed hydropower, but plans call for installing 39,600 MW in the next two decades ([18], "Legal", 62–9). Hydropower as a domestic electricity resource has and continues to serve as an incubator energy source to change the standard of life of the state that turns to harnessing it. Hydropower's past is instructive to evaluate its future while the installation process has been significantly changed.

Data are like guardrails in uncertain mountain terrain. Data serve to project future electricity demand and the construction response is in the form of hydroelectric project construction schedules to meet the anticipated electricity need. Hydroelectric projects are capital demanding and schedule sensitive. Projected construction values provide a road map how different systems anticipate to serve future electricity needs within a given time frame. The world's hydroelectric systems will add 157.8 GW in 2008, and nearly 83% of this expansion is placed in Asia (Table 5). Of the 130 GW in Asia, China builds 80 GW, or 61%. These data serve to illustrate unevenness in distribution globally and regional electricity planning policy differences on how to foster energy autonomy. The dominance of the hydroelectric sector in Asia and South America points to the introduction of energy availability and the industrialization process in these two regions since WWII. Power and change gravitate towards each other.

Norway and Switzerland turned early to hydropower as coal-poor states and turned this energy source into a major agent to change the standard of life for their citizens. In 2000, Norway's reported per capita annual electricity use was 27,600 kWh, Switzerland's 8500 kWh. Currently in Africa, the per capita electricity consumption per year in 2000 was 524 kWh while the world averaged 2475 kWh/p/y (Table 1). These few selected values as reference markers illustrate the impending force of pressure to use local electricity sources—hydropower—to further socioeconomic change. Additional pressure in this process will come out of the urbanization process in Africa. Increased fossil fuel prices contribute their influence to enhance hydropower's rising role in the electricity generating sector. Africa in 2000 had 22,104 MW of installed hydropower (see Table 1), comprising 21.7% of the continents' electricity supply, or 112.2 kWh out of 524 kWh/p/y were hydropower generated. Economic pressures to change this condition can be identified in Ethiopia, which in 2000 had 378 MW of installed hydropower. Two percent of Ethiopia's hydropower potential is actually in use. In 2006, 791 MW were on line, by 2010/11 this is to reach 4000 MW. In 2005 the per capita consumption was 28 kWh/p/y, and 80% of the country's population had no access to electricity. The exploitable potential is 30,000 MW, 4461 MW are under construction or "committed" for construction. The future of hydropower opens the path to change consistent with local conditions and possibly including options similar to those observed in Norway and Switzerland when they got the light.

Hydropower's future in Asia parallels its current economic change. China, India, Iran, and Turkey are turning into major hydropower states. Hydropower development originated in the US and Europe, hence to expect contemporary parallel applications obliges to include the varied time frames of project construction periods. While the Chinese system will be the world's largest, the Indian, Turkish, and Iranian systems are impressive for their respective magnitudes. Also to be included are the S.E. Asian states with significant hydropower resources. It is useful to refer once again to available water volumes in km^3 and m^3/s to identify local hydropower resources (Table 2).

The table of world Electricity Systems points to the pace and magnitude of change covering five decades (Table 4).

Hydropower's future is inseparable from economic evaluations. Cash flow goes into construction without return for the time until a certain quantity of MWs enter service. Cash and interests rates act as constraints upon profligate spending schedules. However, projects today are projected to generate for 100 years+ and the repayment schedule is somewhere from 12 to 25 years. Not included in this assessment projection are transmission and transforming installations. In the economic sphere, it is not only project costs, but also money market conditions within each economic system, hence prediction is made in an unstable economic climate. This leaves the question, how can an economic system function without an effective electricity generating system?

While hydropower has its limitations, there are two options to enhance this energy source: one by turning to run-of-the-river bulbar generation; and two by pumped-storage. This second system is a practical approach to enhance the "hydropower energy bridge." It needs to be noted, the electricity system as in place in 2009 will be notably different in 2050 as technology introduces changed electricity systems in most likelihood phasing out the fossil fuel era in the electricity sector. The run-of-the-river bulbar units can be placed without any dam, notably in very large rivers like the Amazon, Yangtze, Orinoco, Parana, Congo, Lower Mekong.[5] The pumped river projects are already in use and serve as stand-by for peak load demand.

As the world has turned multi-energy source dependent, the need for energy has reduced states' energy autarchy and source

[5] Before large rotor systems can be installed in the rivers cited, pilot studies with experimental units have to serve to identify functional parameters. A step in this direction is underway, on the Mississippi River in Minnesota with a 100 kW hydrokinetic turbine. It is to function in a free moving waterbody without any diversionary structures ([28], First US, 96).

Table 6
World electricity consumption-2004-country grouping based on.

Annual per capita consumption-kWh/p/y and % hydropower derived							
Regions	World	Africa	Asia	Europe	N. America	S. America	Oceania
Per capita kWh	2701, 21%	619, 21%	1588, 20%	5452, 22%	10,021, 15%	2149, 64%	8848, 25%
0–199	39, 18%	30, 57%	6, 35%	N/A	1	N/A	2
200–999	40, 19%	14, 83%	12	N/A	7	2	5
1000–2700	49, 23%	6	15, 29%	4	13, 35%	6	5
2701–5000	31, 15%	3	4	12	7	5	N/A
Over 5000	71, 25%	N/A	N/A	23, 59%	9	1	5, 29%
Count in tabulation	230	53	51	39	37	14	17

UN (2007) 2004 energy statistics yearbook. New York, UN-539-555.

options ([19], ENERGY). Additional energy sources have become the norm in the 1930–2009 period. This will foster the search for a more universal energy-electricity source replacing the energy system familiar in 2009. Hydropower will outlast most of the currently known energy sources because of its favorable economics. It also may be helped by change water management, notably urban–industrial water supply systems, and significantly the dams needed for irrigation projects. Irrigation currently provides 40% of the worlds' food production. To start a hydropower project is expensive, to operate it, it out competes all comers (Table 3).

Hydropower has played a prominent part in the electrification phase of the industrialization process. As the less industrialized states of the world expand their secondary sector, low cost electricity will be sought to further this phase of domestic change. Economy in investment strategy and the inherent advantage of long term low cost electricity supply and rising urbanization rates use hydropowered electricity to service local energy needs. India plans to integrate the national fluvial system by "interconnecting" its key rivers to enhance hydrological management and enlarge its hydropower system by 55,000 MW by 2012. In China hydropower serves as a key link in its evolving energy matrix. Chinese plans call for 158 GW installed in 2010 and 270 GW by 2020. If each kW installed averages $1200, that bill by 2020 will be $134,400,000,000, and this is for 112 GW, not 270 GW. Iran and Turkey pursue a comparable course of action. Brazil has to plan on 4500 MW/year to avoid brownouts or blackouts. The options are limited. China currently (2009) burns annually 43% of the world's coal production, this may illuminate the future for hydropower in China. Current limitations for clean bulk low cost electricity make hydropower the "electricity bridge" to that electricity source four to five decades hence (Table 6). Electricity's future is in the oceans and the sky not in cane sugar or corn fields.[6] Hydropower for its part contributes to ease newcomers to the industrial world into functional electricity depending energy systems.

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Joe's keen eyes and computer skills as always merit fullest recognition.

[6] The topic of bio-fuels in electricity generation may be a peripheral variable, but depending upon the magnitude of production it occupies its place in the U.S. energy matrix. In the US context maize (corn) and sugar cane are the key ethanol sources. If production reaches the 22×10^9 gallons per year in the U.S., by 2022 that would be 1043×10^6 barrels a day or about 5% of fossil fuel needs per day in 2008. Globally to derive a significant percent of energy from biofuels would impose a heavy burden on active agricultural land uses. Bagasse is the biofuel that powers sugarcane processing and is listed in the Brazilian energy matrix. Another aspect to be citied are biofuel base price fluctuations. Vera Sun Energy Corporation, a biofuel-ethanol corn-based firm, reported a $\$476 \times 10^6$ loss for its third quarter [23]. This provides some measure of unpredictability in the available additional energy sources [24].

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